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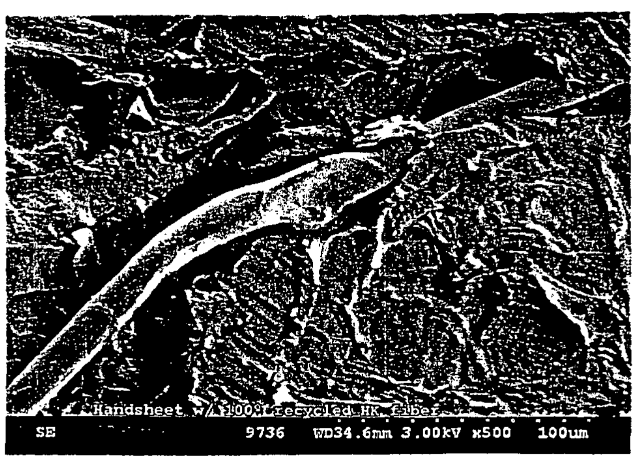

(57) Abstract: A hydraulically entangled nonwoven composite structure that includes a matrix of substantially continuous filaments; and recycled synthetic fibers and fiber-like materials having at least one thread element composed of synthetic material with at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid. This nonwoven composite structure may be used as a wiper or an absorbent material. A method of forming the nonwoven composite structure includes the steps of: (a) providing a layer of recycled synthetic fibers and fiber-like materials having at least one thread element composed of synthetic material containing at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid; (b) superposing the layer of recycled fibers and fiber-like materials over a layer of substantially continuous filaments; (c) hydraulically entangling the layers to form a nonwoven web; and (d) drying the web.

WO 02/38846 A2

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HYDROENTANGLED NONWOVEN COMPOSITE STRUCTURES CONTAINING RECYCLED SYNTHETIC FIBROUS MATERIALS

FIELD OF THE INVENTION

The present invention relates to hydraulically entangled composite structures containing recycled fibers and a method for making a nonwoven composite structure.

BACKGROUND OF THE INVENTION

Although nonwoven webs of pulp fibers are known to be absorbent, nonwoven webs made entirely of pulp fibers may be undesirable for certain applications such as, for example, heavy duty wipers because they lack strength and abrasion resistance.

Pulp fibers have been combined with staple length fibers and hydraulically entangled. However, adding staple fibers increases expense. In addition, suspensions containing staple fibers can be more difficult to process utilizing conventional paper-making or wet-laying techniques. One known technique for combining these materials is by hydraulic entangling. For example, U.S. patent No. 4,808,467 to Suskind discloses a high-strength nonwoven fabric made of a mixture of wood pulp and textile fibers entangled with a continuous filament base web. However, textile fibers still can add expense even when added to combinations of pulp and continuous filaments.

It has been proposed that bonded fibrous webs may be mechanically broken up into smaller pieces such as fiber bundles, threads and/or individual fibers and these pieces then be formed into a web by hydraulic entangling. This is normally accomplished by mechanical tearing and shredding dry material. For example, International Application PCT/SE95/00938 states that it is known to mechanically shred dry nonwoven and textile waste and that dry mixed waste containing both synthetic and natural fibers may be used. According to PCT/SE95/00938, a significant feature of shredding and tearing techniques is that the tearing or shredding operation is often incomplete so that recycled fibers are present partly in the form of discrete bits of the original fabric that may be characterized as “flocks” or

fiber bundles. These flocks are described as providing non-uniformities that give webs containing such flocks a more textile-like appearance.

Flocks and bits of fabric are difficult to process in subsequent operations such as, for example, a wet-laying process, air-laying process, hydraulic entangling process or other web-forming processes. Presence of these non-uniformities may reduce the value of the recycled fibers as well as degrade the appearance, strength, uniformity and other desirable properties of a web or fabric made with the recycled fibers.

In addition, it may be difficult to entangle flocks and discrete bits of fabric with substrates such as, for example, continuous filaments.

Removing the non-uniformities by screening or other techniques reduces the efficiency of the fiber recovery. Additional dry mechanical chopping, shredding, tearing, garnetting or picking operations to reduce the fiber bundles or flocks into fibers or fiber-like material having a length of less than 5 millimeters may be impractical. In addition, the additional mechanical work may transfer so much energy in the form of heat that the dry material may melt into unusable clumps and may diminish or eliminate any environmental or economic advantages initially presented by recycling the material.

SUMMARY OF THE INVENTION

The present invention addresses the needs discussed above by providing a hydraulically entangled nonwoven composite structure that includes a matrix of substantially continuous filaments; and a fibrous material including recycled synthetic fibers and fiber-like materials having at least one thread element composed of synthetic material and including at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid.

The thread element may have a length ranging from about 1 millimeter to about 15 millimeters. For example, the thread element may have a length ranging from about 1.5 to about 10 millimeters. As another example, the thread element may have a length ranging from about 2 to about 5 millimeters. The thread element may have a diameter of less than 100 micrometers. For example, the thread element may have a diameter of less than about 30 micrometers and as a

particular example may have a fiber diameter of from about 10 micrometers to about 20 micrometers.

According to an aspect of the invention, the irregular distortions may be in the form of bends in the thread element, flattened segments of thread element, expanded segments of thread element and combinations thereof. In addition, with recycling, the bends and/or twists provide more effective interlocking of the fibrous web in the entangling process.

Generally speaking, the irregular distortions cause the thread elements of the recycled materials to have greater surface area than thread elements in the bonded fibrous material prior to hydraulic fracture of the thread element to separate it from the bonded fibrous material. For example, the surface areas of the recycled thread elements are at least about 5 percent greater.

In embodiments of the invention, the recycled synthetic fibers and fiber-like materials may be a synthetic material selected from polyesters, polyamides, polyolefins, fiberglass and combinations thereof. In embodiments of the invention, the recycled synthetic fibers and fiber-like materials may be a synthetic thermoplastic material. For example, the synthetic thermoplastic material may be a polyolefin such as polypropylene, polyethylene and combinations of the same. The synthetic thermoplastic material may be in the form of multicomponent fibers, filaments, strands or the like and may include fiber and/or filaments having various cross-sectional shapes, lobes or other configurations.

According to the invention, the matrix of substantially continuous thermoplastic polymer filaments can be a nonwoven web of spunbonded filaments. By way of example only, the nonwoven web of spunbonded filaments may be a nonwoven web of polypropylene spunbonded filaments. As a further example the nonwoven web may be a nonwoven web of bi-component spunbonded filaments.

The matrix of substantially continuous polymer filaments may be composed of thermoplastic polymers selected from polyolefins, polyamides, polyesters, certain polyurethanes, A-B and A-B-A' block copolymers where A and A' are thermoplastic endblocks and B is an elastomeric midblock, copolymers of ethylene and at least one vinyl monomer, unsaturated aliphatic monocarboxylic acids, and esters of such monocarboxylic acids.

If the thermoplastic polymer is a polyolefin, it may be, for example, polyethylene, polypropylene, polybutene, ethylene copolymers, propylene copolymers, butene copolymers and/or blends of the above.

The hydraulically entangled nonwoven composite structure may further include non-recycled natural fibrous materials, non-recycled natural synthetic materials, recycled natural fibrous materials, synthetic pulps, particulate materials and combinations thereof. For example, the hydraulically entangled nonwoven composite structure may further include pulp fibers. In an embodiment of the invention, the hydraulically entangled nonwoven composite structure may contain from about 1 to about 85 percent, by weight of recycled synthetic fibers and fiber-like materials; from about 15 to about 99 percent, by weight of pulp fibers; and from 1 to 30 percent, by weight of substantially continuous filaments.

The pulp fiber component may be woody and/or non-woody plant fiber pulp. The pulp may be a mixture of different types and/or qualities of pulp fibers.

The present invention also contemplates treating the hydraulically entangled nonwoven composite structure with small amounts of materials such as, for example, binders, surfactants, cross-linking agents, de-bonding agents, fire retardants, hydrating agents, pigments, and/or dyes. Alternatively and/or additionally, the present invention contemplates adding particulates such as, for example, activated charcoal, clays, starches, and superabsorbents to the nonwoven composite structure. In one embodiment, the hydraulically entangled nonwoven composite structure may further include up to about 3 percent of a de-bonding agent.

The hydraulically entangled nonwoven composite structure may be used as a heavy duty wiper. In one embodiment, the nonwoven composite structure may be a single-ply or multiple-ply wiper having a basis weight from about 20 to about 200 grams per square meter (gsm). For example, the wiper may have a basis weight between about 25 to about 150 gsm or more particularly, from about 30 to about 110 gsm. The wiper desirably has a water capacity greater than about 450 percent, an oil capacity greater than about 250 percent, a water wicking rate (machine direction) greater than about 2.0 cm per 15 seconds, and oil wicking rate (machine direction) greater than about 0.5 cm per 15 seconds.

The present invention also encompasses a method of making a hydraulically entangled nonwoven composite structure that includes the steps of: (a) providing a layer of recycled synthetic fibers and fiber-like materials having at least one thread element composed of synthetic material containing at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid; (b) superposing the layer of recycled synthetic fibers and fiber-like materials over a layer of substantially continuous filaments; (c) hydraulically entangling the layers to form a nonwoven composite structure; and (d) drying the web.

According to the present invention, the steps of providing the layer of recycled synthetic fiber and fiber-like materials and superposing the layer of recycled synthetic fibers and fiber-like materials over a layer of substantially continuous filaments may involve or include depositing a layer of the recycled fibers and fiber-like materials directly on a layer of substantially continuous filaments by dry forming or wet-forming techniques.

In an embodiment of the invention, the steps of providing the layer of recycled synthetic fiber and fiber-like materials and superposing the layer of recycled synthetic fibers and fiber-like materials over a layer of substantially continuous filaments may involve or include depositing a layer of the recycled fibers and fiber-like materials fiber and fiber-like materials and pulp fibers directly on a layer of substantially continuous filaments by dry forming or wet-forming techniques.

The hydraulic entangling may be carried out by conventional hydraulic entangling techniques.

The hydraulically entangled nonwoven composite structure may be dried utilizing a non-compressive drying process. Through-air drying processes have been found to work particularly well. Other drying processes which incorporate infra-red radiation, yankee dryers, steam cans, vacuum de-watering, microwaves, and ultrasonic energy may also be used.

DEFINITIONS

The term "machine direction" as used herein refers to the direction of travel of the forming surface onto which fibers are deposited during formation of a nonwoven web.

The term "cross-machine direction" as used herein refers to the direction which is perpendicular to the machine direction defined above.

The term "pulp" as used herein refers to fibers from natural sources such as woody and non-woody plants. Woody plants include, for example, deciduous and coniferous trees. Non-woody plants include, for example, cotton, flax, esparto grass, milkweed, straw, jute, hemp, and bagasse.

The term "average fiber length" as used herein refers to an average length of fibers, fiber bundles and/or fiber-like materials determined by measurement utilizing microscopic techniques. A sample of at least 20 randomly selected fibers is separated from a liquid suspension of fibers. The fibers are set up on a microscope slide prepared to suspend the fibers in water. A tinting dye is added to the suspended fibers to color cellulose-containing fibers so they may be distinguished or separated from synthetic fibers. The slide is placed under a Fisher Stereomaster II Microscope - S19642/S19643 Series. Measurements of 20 fibers in the sample are made at 20X linear magnification utilizing a 0-20 mils scale and an average length, minimum and maximum length, and a deviation or coefficient of variation are calculated. In some cases, the average fiber length will be calculated as a weighted average length of fibers (e.g., fibers, fiber bundles, fiber-like materials) determined by equipment such as, for example, a Kajaani fiber analyzer Model No. FS-200, available from Kajaani Oy Electronics, Kajaani, Finland. According to a standard test procedure, a sample is treated with a macerating liquid to ensure that no fiber bundles or shives are present. Each sample is disintegrated into hot water and diluted to an approximately 0.001% suspension. Individual test samples are drawn in approximately 50 to 100 ml portions from the dilute suspension when tested using the standard Kajaani fiber analysis test procedure. The weighted average fiber length may be an arithmetic average, a length weighted average or a weight weighted average and may be expressed by the following equation:

$$\sum_{x_i=0}^{k} (x_i * n_i)/n$$

where k = maximum fiber length

x_i = fiber length

n_i = number of fibers having length x_i

n = total number of fibers measured.

One characteristic of the average fiber length data measured by the Kajaani fiber analyzer is that it does not discriminate between different types of fibers. Thus, the average length represents an average based on lengths of all different types, if any, of fibers in the sample.

As used herein, the term "spunbonded filaments" refers to small diameter continuous filaments which are formed by extruding a molten thermoplastic material as filaments from a plurality of fine, usually circular, capillaries of a spinnerette with the diameter of the extruded filaments then being rapidly reduced as by, for example, eductive or mechanical drawing and/or other well-known spunbond mechanisms. The production of spun-bonded nonwoven webs is illustrated in patents such as, for example, in U.S. Patent No. 4,340,563 to Appel et al., and U.S. Patent No. 3,692,618 to Dorschner et al. The disclosures of these patents are hereby incorporated by reference.

As used herein, the term "meltblown fibers" means fibers formed by extruding a molten thermoplastic material through a plurality of fine, usually circular, die capillaries as molten threads or filaments into a high velocity gas (e.g. air) stream which attenuates the filaments of molten thermoplastic material to reduce their diameter, which may be to microfiber diameters. Thereafter, the meltblown fibers are carried by the high velocity gas stream and are deposited on a collecting surface to form a web of randomly disbursed meltblown fibers. Such a process is disclosed, for example, in U.S. Patent No. 3,849,241 to Butin, the disclosure of which is hereby incorporated by reference.

As used herein, the term "microfibers" means small diameter fibers having an average diameter not greater than about 100 microns; for example, having a diameter of from about 0.5 microns to about 50 microns, more particularly,

microfibers may have an average diameter of from about 1 micron to about 40 microns.

As used herein, the term "thermoplastic material" refers to a polymer that softens when exposed to heat and returns to generally its un-softened state when cooled to room temperature. Natural substances which exhibit this behavior are crude rubber and a number of waxes. Other exemplary thermoplastic materials include, without limitation, polyvinyl chlorides, some polyesters, polyamides, polyfluorocarbons, polyolefins, some polyurethanes, polystyrenes, polyvinyl alcohols, caprolactams, copolymers of ethylene and at least one vinyl monomer (e.g., poly(ethylene vinyl acetates), copolymers of ethylene and n-butyl acrylate (e.g., ethylene n-butyl acrylates), polylactic acids, thermoplastic elastomers and acrylic resins.

As used herein, the term "non-thermoplastic material" refers to any material which does not fall within the definition of "thermoplastic material" above.

As used herein, the term “substantially continuous filaments” generally refers to melt-spun, solution-spun or drawn filaments having a generally indeterminate or continuous length during manufacture and when deposited and collected to form a web or matrix of filaments. Generally speaking, spunbond filaments are typically considered to be substantially continuous filaments unless the manufacturing process has been modified to produce short discrete segments or by chopping or cutting the filaments into readily measurable lengths such as lengths typically associated with textile or staple fibers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a photomicrograph of a detail of an exemplary recycled synthetic fiber of the type used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 2 is a photomicrograph of a detail of an exemplary virgin synthetic staple fiber.

FIG. 3 is a photomicrograph of a detail of an exemplary recycled synthetic fiber of the type used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 4 is a photomicrograph of a detail of an exemplary recycled synthetic fiber of the type used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 5 is a photomicrograph of a detail of an exemplary recycled synthetic fiber of the type used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 6 is a photomicrograph of a detail of an exemplary recycled synthetic fiber of the type used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 7 is a photomicrograph of a detail of an exemplary virgin synthetic staple fiber.

FIG. 8 is a photomicrograph of a detail of multiple exemplary recycled synthetic fibers of the type used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 9 is a photomicrograph of a detail of an exemplary recycled synthetic fiber of the type that may be used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 10 is a photomicrograph showing details of exemplary recycled synthetic fibers of the type that may be used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 11 is a photomicrograph showing details of exemplary recycled synthetic fibers of the type that may be used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

FIG. 12 is a photomicrograph showing details of exemplary recycled synthetic fibers of the type that may be used in the formation of an exemplary hydraulically entangled nonwoven composite structure.

DETAILED DESCRIPTION OF THE INVENTION

The present invention encompasses a hydraulically entangled nonwoven composite structure that includes a matrix of substantially continuous filaments and recycled synthetic fibers and fiber-like materials entangled and intertwined in the matrix of filaments. The synthetic fibers and fiber-like materials are recovered from bonded fibrous materials that are converted into substantially individual fibers

and fiber-like materials. Importantly, these bonded fibrous materials are materials that include synthetic fibers and may be bonded fibrous materials such as, for example, woven fabrics, knitted fabrics, nonwoven webs and combinations thereof. As a further example, the recycled fibers may come from nonwoven webs that are thermally bonded, adhesively bonded, mechanically entangled, solvent bonded, hydraulically entangled and/or combinations of such techniques and may contain synthetic fibrous materials, natural fibrous materials and combinations thereof. The synthetic fibrous material may include thermoplastic fibers and filaments.

In order to recover useable recycled synthetic fibers for hydraulic entangling, bonded fibrous webs are cut or shredded into pieces having sizes that are adapted for suspension in a liquid. Next, the pieces are suspended in liquid and mechanical work is applied to the liquid suspension of discrete pieces to generate hydraulic pressure and mechanical shear stress conditions sufficient to hydraulically fragment the bonded fibrous materials into fibers and fiber-like components. Finally the substantially individual fibers and fiber-like components are separated from the liquid.

The bonded fibrous materials may be converted into discrete pieces by a conventional operation such as, for example, mechanical shredding, mechanical cutting, mechanical tearing, mechanical grinding, pulverizing, water jet cutting, laser cutting, garnetting and combinations thereof.

Importantly, a liquid suspension of these pieces is exposed to conditions of hydraulic pressure, shear stress and/or cavitational forces sufficient to fragment, rupture, rupture, burst or disintegrate pieces of bonded fibrous materials into useful free fibers and fiber bundles or fiber-like materials. These process conditions used to convert the shredded material to recycled fibers are more aggressive and stringent than those found in conventional pulping operations.

As an example, normal pulping operations typically use less than about 3 horsepower-day (24 hours) per dry ton of material. Embodiments of the present invention may utilize much larger inputs of energy. According to the invention, the approximate amount of mechanical work applied to the liquid suspension may be greater than about 3 Horsepower – day (24 hours) per dry ton of bonded fibrous material – as determined by measuring the electric current drawn by the motor providing movement to the components generating hydraulic pressure and shear

stress conditions. This number may be greater than 4 Horsepower – day per ton and may be even greater than 6 or more. For example, the method of the invention may be practiced utilizing 35% more energy; 50% percent more energy, or even more to separate useful free fibers and fiber bundles from the bonded fibrous material. It is contemplated that, in some situations or under some conditions, the approximate amount of mechanical work may be less than 3 Horsepower – day per dry ton of bonded fibrous material.

Although the inventors should not be held to a particular theory of operation, it is believed that the combination of hydraulic pressure, shear stress, and cavitational forces breaks up the material into free fibers and fiber bundles. It is also thought that the content of free fibers and the average size of the bundles can be controlled by varying the pressure and mechanical stress. It is generally thought that this high level of mechanical action or work is possible without causing significant degradation of the synthetic components of the bonded fibrous materials (e.g., without melting synthetic thermoplastic material) because the water/liquid in the process absorbs the heat generated as free fibers and fiber-like materials are separated from the bonded fibrous material.

Generally speaking, conventional beating and/or refining equipment is used to modify cellulose fibers to develop papermaking properties of hydration and fibrillation. According to the present invention, conventional beaters and/or refiners may be configured or operated in an unconventional manner to provide the hydraulic pressure and shear stress conditions sufficient to fragment and fracture the bonded fibrous material into free fibers, fiber bundles and fiber-like materials. Exemplary beater devices are available from manufacturers such as Beloit Jones, E. D. Jones, Valley, and Noble & Wood.

A liquid suspension of bonded fibrous material pieces is introduced into the beater device. Alternatively and/or additionally, bonded fibrous material pieces may be introduced directly into liquid in the beater vat. Various proportions of bonded fibrous materials and water may be used and one skilled in the art may determine appropriate proportions.

During operation, the cylinder roll is rotated so that sufficient hydraulic pressure and shear stress are produced between its blades or vanes and the blades mounted on the fixed plate.

Rotation speed, consistency of the suspension in the vat and clearance between the rotating blades or vanes and the fixed blades is also adjusted to conditions that enhance "metal to fiber" interaction that cuts or controls the length of free fibers, fiber bundles and fiber-like particles. The term "metal to fiber" interaction is used to describe the contact between the bonded fibrous material and the fixed and/or rotating blades that may occur under conditions of hydraulic pressure and mechanical shear stress sufficient to sever, cut or break long fibers. According to the invention, this interaction should be controlled to cut long fibers without materially affecting or lowering the length and/or freeness of pulp or short fibers that may be present in the suspension.

While equipment may be operated to provide fibers, fiber bundles and fiber-like materials having a wide range of lengths, it may also be used to generate fiber and fiber-like material having an average length distribution that spans approximately 7 millimeters or less. Generally speaking, a more uniform fiber distribution tends to enhance processing and hydraulic entangling. However, it is contemplated that a mix of longer fibers and shorter fibers may be desirable. The longer fibers may have advantages in providing strength and shorter fibers may have advantages in providing other useful characteristics such as, for example, absorbency, hand, drape and/or bulk.

In addition to controlling length, some "metal to fiber" interaction may generate deformations and distortions of synthetic components of the bonded fibrous material. While some deformations and distortions may be generated by hydraulic fragmentation of the bonded fibrous material others may be generated by tearing, slicing and breaking of fiber and/or filaments. These fiber deformations and irregularities are thought to help wet forming (or dry forming) of a web as well as subsequent hydraulic entangling. These characteristics of the recycled fibers and fiber-like materials enhance their utility in hydraulic entangling processes and make it practical to produce hydraulically entangled fabric that may exhibit the same or similar physical properties as one produced from 100 percent virgin fibers and potentially exceed those properties.

A discussion of the recycled synthetic fibers is useful to understanding the hydraulically entangled fabrics constructed from these fibers. Referring now to FIGS. 1, 3-6, and 8-12, there are shown various exemplary recycled synthetic

fibers, fiber bundles and/or fiber-like materials having at least one thread element composed of synthetic material having at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid.

The thread element is discontinuous and, as an example, may have a length ranging from about 1 millimeter to about 15 millimeters. For example, the thread element may have a length ranging from about 1.5 to about 10 millimeters. As another example, the thread element may have a length ranging from about 2 to about 5 millimeters. The thread element may have a diameter of less than 100 micrometers. For example, the thread element may have a diameter of less than 30 micrometers. Generally speaking, these dimensions are similar to certain varieties of commercially available pulps and may be readily blended with commercial pulps. In some embodiments, the thread elements may have a diameter of less than 10 microns and may even be less than 1 micron.

The irregular distortions may be in the form of bends in the thread element, flattened segments of thread element, expanded segments of thread element and combinations thereof.

Generally speaking, the irregular distortions cause the thread elements of the recycled materials to have greater surface area than thread elements in the bonded fibrous material prior to hydraulic fracture of the thread element to separate it from the bonded fibrous material. For example, the surface areas of the recycled thread elements may be at least about 5 percent greater. The increased surface area will often be the result of remaining fiber bond areas, cross-over points, flat areas, fiber distortions and the like.

FIG. 1 is a photomicrograph (approximately 500X linear magnification) showing a detail of an exemplary recycled synthetic fiber. The recycled fiber was recovered from a composite structure containing a thermally point bonded continuous polypropylene filament web and pulp fibers hydraulically entangled with the continuous filament web. The fiber visible in the center of the photomicrograph is a spunbonded polypropylene thread element having bends in the filaments and a relatively flattened segment. At least a portion of these distortions, e.g. flattened sections, are generated or exposed by hydraulic fracture of the thread element from the bonded continuous polypropylene fiber web along with the cellulose pulp

(i.e., the composite structure). The material surrounding the thread element is cellulose pulp.

FIG. 2 is a photomicrograph (approximately 500X linear magnification) showing conventional polypropylene staple fibers appearing in a conventional bonded carded web structure. In contrast to the thread elements of FIG. 1, these fibers appear relatively free of irregular distortions. The fibers have relatively smooth surfaces, even or uniform diameters, and lack the twists, bends, kinks and other irregular distortions that are evident in the thread element shown in FIG. 1.

FIG. 3 is a photomicrograph (approximately 120X linear magnification) showing a detail of an exemplary recycled synthetic fiber recovered from the same type of composite structure as the thread element shown in FIG. 1. The fiber visible across the central region of the photomicrograph is a polypropylene thread element that exhibits a loop and bends as well as relatively flattened segments. At least a portion of these distortions are generated or exposed by hydraulic fracture of the thread element from the bonded fibrous material (i.e., the composite structure). The material surrounding the thread element is cellulose pulp.

FIG. 4 is a photomicrograph (approximately 120X linear magnification) showing a detail of an exemplary recycled synthetic fiber recovered from the same type of composite structure as the thread element shown in FIG. 1. The fiber visible in the center of the photomicrograph is a polypropylene thread element. The arrow in the photomicrograph points to a sharp bend in the thread element.

FIG. 5 is a photomicrograph (approximately 500X linear magnification) showing a detail of an exemplary recycled synthetic fiber recovered from the same type of composite structure as the thread element shown in FIG. 1. The fiber visible in the center of the photomicrograph is a polypropylene thread element that exhibits bends and/or twists as well as a roughened segment.

FIG. 6 is a photomicrograph (approximately 500X linear magnification) showing a detail of an exemplary recycled synthetic fiber recovered from the same type of composite structure as the thread element shown in FIG. 1. The fiber visible across the center of the photomicrograph is a polypropylene thread element showing a cut end of the fiber that is flattened and expanded.

FIG. 7 is a photomicrograph (approximately 500X linear magnification) showing a detail of a conventional polypropylene staple fiber. In contrast to the

thread element of FIG. 6, the fiber appears relatively free of irregular distortions and has an end that appears to be cut cleanly without evidence of expansion or other distortion.

FIG. 8 is a photomicrograph (approximately 250X linear magnification) showing a detail of two exemplary recycled synthetic fibers recovered from the same type of composite structure as the thread element shown in FIG. 1. The fibers visible across the center and near the lower portion of the photomicrograph are polypropylene thread elements that exhibit bends as well as roughened segments.

FIG. 9 is a photomicrograph (approximately 500X linear magnification) showing a detail of exemplary recycled synthetic fibers. The recycled fibers were recovered from Kimtex® brand wiper containing thermally point-bonded web of polypropylene meltblown fibers. The relatively fine meltblown fibers visible in the center of the photomicrograph are polypropylene thread elements having bends, twists, tangles and relatively flattened segments. At least a portion of these distortions are generated or exposed by hydraulic fracture of the thread elements from the bonded fibrous material (i.e., the Kimtex® wiper). The material surrounding the thread elements is cellulose pulp.

FIG. 10 is a photomicrograph (approximately 100X linear magnification) showing a detail of exemplary recycled synthetic fibers recovered from the same type of material as the thread elements shown in FIG. 9. A bond point approximately 500 micrometers in length is visible in the center of the photomicrograph. Fibers radiate outward from the edges of the bond point in the form of polypropylene thread elements having bends, twists, tangles and relatively flattened segments. At least a portion of these distortions are generated or exposed by hydraulic fracture of the thread elements from the bonded fibrous material. Some of the material in the background of the thread elements is cellulose pulp.

FIG. 11 is a photomicrograph (approximately 500X linear magnification) showing a detail of exemplary recycled synthetic fibers recovered from the same type of material as the thread elements shown in FIG. 10. A larger fiber-like material or fiber bundle is approximately 40 micrometers in width is visible in the center of the photomicrograph. Fibers surround and radiate outward from the

edges of the fiber-like material or fiber bundle in the form of polypropylene thread elements having bends, twists, tangles and relatively flattened segments. At least a portion of these distortions are generated or exposed by hydraulic fracture of the thread elements from the bonded fibrous material. The larger fibrous materials near the thread elements are cellulose pulp fibers.

FIG. 12 is a photomicrograph (approximately 500X linear magnification) showing a detail of exemplary recycled synthetic fibers recovered from the same type of material as the thread elements shown in FIG. 10. A mix of cellulose pulp and recycled fibers in the form of polypropylene thread elements having bends, twists, tangles and relatively flattened segments is shown.

The hydraulically entangled nonwoven composite structure containing the recycled fibers and fiber-like materials may be made by conventional hydraulic entangling techniques. For example, a dilute suspension of recycled fibers and fiber-like materials may be supplied by a head-box and deposited via a sluice in a uniform dispersion onto a forming fabric of a conventional papermaking machine.

The suspension of fibers may be diluted to any consistency which is typically used in conventional papermaking processes. For example, the suspension may contain from about 0.01 to about 1.5 percent by weight fibers suspended in water. Water is removed from the suspension of fibers to form a uniform layer. The recycled fibers may also include added pulp fiber and/or other types of fibers, particulates or other materials. It is contemplated that the recycled fibers and these various fibers and/or other material may be formed into a stratified or heterogeneous sheet or layer. Alternatively and/or additionally, these components may be blended or mixed to form a homogenous layer.

Small amounts of wet-strength resins and/or resin binders may be added to improve strength and abrasion resistance if there is a cellulose component in the fibers. Useful binders and wet-strength resins include, for example, Kymene 557 H available from the Hercules Chemical Company and Parez 631 available from American Cyanamid, Inc. In some cases, it may be possible to add cross-linking agents and/or hydrating agents to the fibers. It is also possible to add debonding agents. One exemplary debonding agent is available from the Quaker Chemical Company, Conshohocken, Pennsylvania, under the trade designation Quaker 2008.

A matrix of substantially continuous thermoplastic polymer filaments (which may be in the form of, for example, a nonwoven web of spunbonded filaments) may be unwound from a supply roll so that it is in position to receive the layer of recycled fibers and fiber-like materials.

Generally speaking, the matrix of substantially continuous thermoplastic polymer filaments may be formed by known continuous filament nonwoven extrusion processes, such as, for example, known solvent spinning or melt-spinning processes, and directly into the process without first being stored on a supply roll. The matrix of substantially continuous thermoplastic polymer filaments is desirably a nonwoven web of continuous melt-spun filaments formed by the spunbond process. The spunbond filaments may be formed from any thermoplastic, melt-spinnable polymer, co-polymers or blends thereof. For example, the spunbond filaments may be formed from such thermoplastic polymers as polyolefins, polyamides, polyesters, polyurethanes, A-B and A-B-A' block copolymers where A and A' are thermoplastic endblocks and B is an elastomeric midblock, copolymers of ethylene and at least one vinyl monomer (such as, for example, vinyl acetates), unsaturated aliphatic monocarboxylic acids, and esters of such monocarboxylic acids. If the substantially continuous filaments are formed from a polyolefin such as, for example, polypropylene, the nonwoven web may have a basis weight from about 3.5 to about 70 grams per square meter (gsm). More particularly, the nonwoven web may have a basis weight from about 10 to about 35 gsm. The polymers may include additional materials such as, for example, pigments, antioxidants, flow promoters, stabilizers and the like.

The matrix of substantially continuous thermoplastic polymer filaments is a matrix of substantially continuous thermoplastic polymer bi-component or multi-component filaments. For example, the matrix of bi-component or multi-component filaments may be a nonwoven web of bi-component or multi-component spunbonded filaments. These bi-component or multi-component filaments may have side-by-side, sheath-core or other configurations. Description of such filaments and a method for making the same may be found in, for example, U.S. Patent No. 5,382,400, in the name of R. D. Pike, et al., and entitled "Nonwoven Multi-component Polymeric Fabric and Method for Making the Same", the disclosure of which is hereby incorporated by reference. Exemplary nonwoven webs of bi-

component or multi-component spunbonded filaments may be available from Kimberly-Clark Corporation, Roswell, Georgia.

The matrix of substantially continuous thermoplastic polymer filaments may be thermally bonded (i.e., pattern bonded) before the layer of fibrous material is superposed on it. Desirably, the matrix of substantially continuous thermoplastic polymer filaments will have a total bond area of less than about 30 percent and a uniform bond density greater than about 100 bonds per square inch. For example, the matrix of substantially continuous thermoplastic polymer filaments may have a total bond area from about 2 to about 30 percent (as determined by conventional optical microscopic methods) and a bond density from about 250 to about 500 pin bonds per square inch.

Such a combination total bond area and bond density may be achieved by bonding the matrix of substantially continuous thermoplastic polymer filaments with a pin bond pattern having more than about 100 pin bonds per square inch which provides a total bond surface area of less than about 30 percent when fully contacting a smooth anvil roll. Desirably, the bond pattern may have a pin bond density from about 250 to about 350 pin bonds per square inch and a total bond surface area from about 10 percent to about 25 percent when contacting a smooth anvil roll.

An exemplary bond pattern has a pin density of about 306 pins per square inch. Each pin defines a square bond surface having sides which are about 0.025 inch in length. When the pins contact a smooth anvil roller they create a total bond surface area of about 15.7 percent. Generally speaking, a high basis weight matrix of substantially continuous thermoplastic polymer filaments tends to have a bond area which approaches that value. A lower basis weight matrix tends to have a lower bond area.

Another exemplary bond pattern has a pin density of about 278 pins per square inch. Each pin defines a bond surface having 2 parallel sides about 0.035 inch long (and about 0.02 inch apart) and two opposed convex sides - each having a radius of about 0.0075 inch. When the pins contact a smooth anvil roller they create a total bond surface area of about 17.2 percent.

Yet another exemplary bond pattern has a pin density of about 103 pins per square inch. Each pin defines a square bond surface having sides which are about

0.043 inch in length. When the pins contact a smooth anvil roller they create a total bond surface area of about 16.5 percent.

Although pin bonding produced by thermal bond rolls is described above, the present invention contemplates any form of bonding which produces good tie down of the filaments with minimum overall bond area. For example, thermal bonding, through-air bonding and/or latex impregnation may be used to provide desirable filament tie down with minimum bond area. Alternatively and/or additionally, a resin, latex or adhesive may be applied to the nonwoven continuous filament web by, for example, spraying or printing, and dried to provide the desired bonding.

The layer of recycled synthetic fibers and fiber-like material is then laid on the nonwoven web which rests upon a foraminous entangling surface of a conventional hydraulic entangling machine. It is desirable that the layer of recycled synthetic fibers is between the nonwoven web and the hydraulic entangling manifolds (i.e., on top of the nonwoven web). The layer of recycled synthetic fibers and fiber-like material and nonwoven web then pass under one or more hydraulic entangling manifolds and are treated with jets of fluid to entangle the recycled fibers with the filaments of the continuous filament nonwoven web. The jets of fluid also drive recycled synthetic fibers into and partially through the nonwoven web to form the hydraulically entangled nonwoven composite structure.

Alternatively, hydraulic entangling may take place while the layer of recycled synthetic fibers and fiber-like materials and the nonwoven web are on the same foraminous screen (i.e., mesh fabric) which the wet-laying took place. The present invention also contemplates superposing a dried sheet of the recycled synthetic fibers and fiber-like material (which may include pulp fibers) on a continuous filament nonwoven web, rehydrating or wetting the dried sheet to a specified consistency and then subjecting the rehydrated or wetted sheet to hydraulic entangling.

The hydraulic entangling may take place while the layer of recycled synthetic fibers and fiber-like material is highly saturated with water. For example, the layer of recycled synthetic fibers may contain up to about 90 percent by weight water just before hydraulic entangling. Alternatively, the layer of recycled fibers may be, for example, an air-laid or dry-laid layer having little or no liquid present. Hydraulic entangling a wet-laid layer of recycled synthetic fibers is desirable because the

fibrous material can be embedded or integrated into and/or entwined and tangled in the matrix of substantially continuous, thermoplastic polymer filaments. If the recycled synthetic fibers includes pulp fibers, hydraulic entangling a wet-laid layer is particularly desirable because it integrates the pulp fibers into the matrix of substantially continuous filaments without interfering with "paper" bonding (sometimes referred to as hydrogen bonding) since the pulp fibers are maintained in a hydrated state.

The hydraulic entangling may be accomplished utilizing conventional hydraulic entangling equipment such as may be found in, for example, in U.S. Patent No. 3,485,706 to Evans, the disclosure of which is hereby incorporated by reference. The hydraulic entangling of the present invention may be carried out with any appropriate working fluid such as, for example, water. The working fluid flows through a manifold which evenly distributes the fluid to a series of individual holes or orifices. These holes or orifices may be from about 0.003 to about 0.015 inch in diameter. For example, the invention may be practiced utilizing a manifold produced by Honeycomb Systems Incorporated of Biddeford, Maine, containing a strip having 0.007 inch diameter orifices, 30 holes per inch, and 1 row of holes. Many other manifold configurations and combinations may be used. For example, a single manifold may be used or several manifolds may be arranged in succession.

In the hydraulic entangling process, the working fluid passes through the orifices at a pressures ranging from about 200 to about 2000 pounds per square inch gauge (psig). At about 2000 psig, it is contemplated that the nonwoven composite structures may be processed at speeds of about 1000 feet per minute (fpm). The fluid impacts the fiber layer which is supported by a foraminous surface which may be, for example, a single plane mesh having a mesh size of from about 40 X 40 to about 100 X 100. The foraminous surface may also be a multi-ply mesh having a mesh size from about 50 X 50 to about 200 X 200. As is typical in many water jet treatment processes, vacuum slots may be located directly beneath the hydro-needling manifolds or beneath the foraminous entangling surface downstream of the entangling manifold so that excess water is withdrawn from the hydraulically entangled material.

Although the inventors should not be held to a particular theory of operation, it is believed that the columnar jets of working fluid which directly impact the relatively

distorted, twisted and high surface area recycled synthetic fibers laying on the continuous filament web work to entangle and intertwine those fibers with each other (and with other fibers that may be present such as, for example, pulp fibers) and with the continuous filaments.

Generally speaking, it is thought that the various irregularities of the central thread element and any branching thread elements, fibrils or the like help the recycled synthetic fibers entangle and intertwine with the continuous filaments and form a coherent entangled matrix. When recycled synthetic fibers are mixed with pulp fibers, this matrix is thought to help secure the pulp fibers.

After the fluid jet treatment, the hydraulically entangled composite structure may be transferred to a non-compressive drying operation. A differential speed pickup roll may be used to transfer the material from the hydraulic needling belt to a non-compressive drying operation. Alternatively, conventional vacuum-type pickups and transfer fabrics may be used. If desired, the composite structure may be wet-creped before being transferred to the drying operation. Non-compressive drying of the entangled composite structure may be accomplished utilizing a conventional rotary drum through-air drying apparatus. The temperature of the air forced through the hydraulically entangled fabric by the through-dryer may range from about 200 to about 500 F. Other useful through-drying methods and apparatus may be found in, for example, U.S. Patent Nos. 2,666,369 and 3,821,068, the contents of which are incorporated herein by reference.

Although through-air drying processes have been found to work particularly well, other drying processes which incorporate infra-red radiation, yankee dryers, steam cans, vacuum de-watering, microwaves, and ultrasonic energy may also be used.

It may be desirable to use finishing steps and/or post treatment processes to impart selected properties to the hydraulically entangled composite structure.. For example, the fabric may be lightly pressed by calender rolls, creped or brushed to provide a uniform exterior appearance and/or certain tactile properties. Alternatively and/or additionally, chemical post-treatments such as, adhesives or dyes may be added to the fabric.

In one aspect of the invention, the hydraulically entangled composite structure may contain various materials such as, for example, activated charcoal, clays,

starches, and superabsorbent materials. For example, these materials may be added to the suspension of recycled synthetic fibers used to form the fiber layer. These materials may also be deposited on the fiber layer prior to the fluid jet treatments so that they become incorporated into the hydraulically entangled composite structure by the action of the fluid jets. Alternatively and/or additionally, these materials may be added to the hydraulically entangled composite structure after the fluid jet treatments.

Test Methods

Trapezoidal tear strengths of samples were measured in accordance with ASTM Standard Test D 1117-14 except that the tearing load is calculated as an average of the first and the highest peak loads rather than an average of the lowest and highest peak loads.

Water capacities of samples were measured generally in accordance with Federal Specification No. UU-T-595C on industrial and institutional towels and wiping papers. The absorptive capacity refers to the capacity of a material to absorb liquid over a period of time and is related to the total amount of liquid held by a material at its point of saturation. Absorptive capacity is determined by measuring the increase in the weight of a material sample resulting from the absorption of a liquid. Absorptive capacity may be expressed, in percent, as the weight of liquid absorbed divided by the weight of the sample by the following equation:

Total Absorptive Capacity = [(saturated sample weight - sample weight)/sample weight] X 100.

The basis weights of samples were determined essentially in accordance with ASTM D-3776-9 with the following changes: 1) sample size was at least 20 square inches (130 cm^2); and 2) a minimum of three random specimens were tested for each sample.

The drape stiffness of samples was measured in accordance with ASTM D1388 except that the sample size is 1 inch by 8 inches.

Bulk (i.e., thickness) of a sample was measured essentially in accordance with TAPPI 402 om-93 and T 411 om-89 utilizing a Emveco 200-A Tissue Caliper Tester. The tester was equipped with a 56.42 mm diameter foot having an area of 2500 mm^2. A stack of 10 samples was tested at a load of 2.00 kPa and a dwell time of 3 seconds.

Abrasion resistance testing was conducted utilizing a Taber Abraser, Model No. 5130 (rotary head, double head abrader) with Model No. E 140-15 specimen holder available from Teledyne Taber of North Tonawanda, New York, generally in accordance with Method 5306 Federal Test Methods Standard No. 191A and ASTM Standard: D 3884 Abrasion Resistance of Textile Fabrics. Sample size measured about 5 inches by 5 inches. Samples were subjected to abrasion cycles under a head weight of about 250 grams. Each abradant head was loaded with a non-resilient, vitrified, Calibrade grinding wheel No. H-18, medium grain/medium bond. Abradant heads were vacuumed after each specimen and resurfaced after each sample (generally about 4 specimens). Resurfacing of abradant heads was carried out with a diamond wheel resurfacer. The abrasion test measured the number of cycles needed to form a 1/2 inch hole through the sample.

Example

This example relates to recycling a bonded and entangled composite material containing natural fibers and synthetic filaments, introducing the material into the furnish stream of a wet forming process, depositing the material onto a nonwoven continuous filament substrate and then hydraulically entangling the materials together to form a hydraulically entangled composite structure.

A composite hydraulically entangled material containing virgin wood pulp and a continuous web of bonded synthetic polypropylene filaments (approximately 20 percent, by weight) (i.e., a spunbond continuous filament web) - available from the Kimberly-Clark Corporation, Roswell, Georgia under the trademarks WYPALL® WORKHORSE® manufactured rags and HYDROKNIT® fast absorbing materials - was shredded into pieces ranging from about 10 - 350mm in length and 3 – 70mm in width. The composite contained approximately 80% by weight pulp and about 20 percent, by weight, polypropylene filaments. The material was shredded utilizing a shredder available from the East Chicago Machine Tool Company, East

Chicago, IN. The pieces were transferred to a conventional Hollander-type industrial beater manufactured by E.D. Jones & Sons, Pittsfield, MA. The beater was a "Number 3 Jones Beating Unit" equipped with a 45 degree diagonal bed plate. The beater had a rotating roll with blades or vanes generally aligned on the roll. The blades or vanes were approximately 1/4 inch (~6 mm) wide, approximately 1/2 inch (~12 to 13 mm) high. These were spaced approximately 1/2 inch (~12 to 13 mm) apart on the exterior of the roll perpendicular to the direction or plane of rotation. A fixed plate was mounted just below the rotating roll and was equipped with blades or "knives" that were approximately 1/8 inch (~3mm) wide, 1/4 inch (~6 mm) high, spaced approximately 3/8 inches (~9 to 10 mm) apart. These were aligned at an angle of 45 degrees to the direction or plane of rotation.

The rotating roll had a diameter of 72 inches, a width of 72 inches, 192 blades each having a length of 72 inches and spaced one-half inch apart. The roll weighed approximately 16 tons. Generally speaking, the speed of rotation is constant and the variable that is modified is the pressure or load on the roll. The roll was mounted such that a gauge pressure reading of 0 psi corresponded to very little or no portion of the weight of the roll (~0 tons) counteracting the force generated by fibers and pieces of bonded fibrous material as they squeezed as they passed through the gap existing between the blades at the bottom of the rotating roll and the fixed blades mounted underneath the roll. A gauge pressure reading of 50 psi corresponded to approximately one-half of the weight of the roll (~8 tons) counteracting the pressure generated fibers and pieces of bonded fibrous material as they squeezed through the gap existing between the blades at the bottom of the rotating roll and the fixed blades mounted underneath the roll. A gauge pressure reading of 100 psi corresponded to approximately the full weight of the roll (~16 tons) counteracting the pressure generated by fibers and pieces of bonded fibrous material as they squeezed through the gap existing between the blades at the bottom of the rotating roll and the fixed blades mounted underneath the roll.

Water was added to the shredded material and hydraulic pressure and shear stress was applied to the material in the Hollander-type beater in two stages. Hydraulic pressure and shear stress was controlled by adjusting the load

on the roll as it rotated. In this particular arrangement, hydraulic pressure and shear stress is generated by a "paddle wheel" type pumping action produced when the beater roll rotates and its attached blades or vanes force liquid and wet material against a fixed plate with blades mounted diagonally to the direction or plane of rotation. Generally speaking, a greater load applied to the rotating roll produces less clearance between the rotating roll and the fixed plate. This corresponds to greater levels of hydraulic pressure and shear stress.

During the first stage, the pressure or load against the rotating roll was 0 pounds per square inch gauge (psig) for 10 minutes. Essentially, no load was applied and the "paddle wheel" action of the rotating roll squeezed the pieces in the suspension through a gap of about 1 cm or more between blades of the rotating roll and blades mounted on the fixed plate. Generally speaking, the first stage was used to wet the shredded material and separate the natural fibers from the synthetic fibers. The consistency was adjusted to be about 3.3 percent (the percentage by weight of air or oven dry fibrous material in the suspension).

During the second stage, conditions were adjusted to establish small zones of very high hydraulic pressure, shear stress and possibly cavitation forces between the moving blades on the rotating roll and fixed blades near or at their closest point of contact. These small zones are thought to generate a micro-bursting action on the shredded bonded fibrous material to hydraulically fragment and/or blow apart and reduce the resulting synthetic fiber length. In addition, the hydraulic fragmentation and "metal to fiber" or "metal to bonded fibrous material" contact controls the length of the longer synthetic filaments without materially affecting or lowering the length and/or freeness of pulp or short fibers in the suspension. In this example, the specific objective was to control the length of the synthetic fibers so the length is maximized while still producing a sheet with uniform appearance and physical properties and without materially lowering the length or freeness of pulp fibers that may be present in the suspension.

In the second stage, pressure on the gauge for the rotating roll was increased to 50 psig and the clearance between the blades of the rotating roll and the fixed plates decreased to between 1 and 10 mm and approximately one-half of the weight of the 16 ton roll (~8 tons) was available to counteract the pressure

generated by fibrous pieces as they were squeezed through the gap between the roll and the fixed plate. These conditions were maintained for 50 minutes.

After treatment, samples of the free fibers, fiber bundles and fiber-like materials were examined microscopically. Natural or pulp fibers were separated and measured separately from the synthetic fibers. In this example, average fiber length was determined as previously described - by manually separating a random sample of 20 synthetic fibers and 20 pulp fibers, measuring the length of individual fibers utilizing a microscope, and then calculating an average length. The resulting recycled fibers and fiber-like materials had the following characteristics:

- The average length of the synthetic fiber was approximately the same length as the wood pulp fibers. Average length of the synthetic fibers was 4.21 mm. The length of individual fibers in the sample ranged from 2.54 to 7.11 mm. It should be noted that, prior to processing, the synthetic fibers initially were substantially continuous polypropylene filaments having indeterminate lengths or lengths at least far exceeding 7.11 mm. The average fiber length for the pulp component was 2.7 mm. The length of individual pulp fibers in the sample ranged from 1.52 to 3.94 mm.

- The wood pulp fiber freeness shows a slight reduction (about 10 percent) indicating that some additional surface area was developed on the wood pulp fiber component of the composite. However the fiber length was not affected.

- Substantial numbers of synthetic fibers have increased surface area as a result of the remaining individual fiber bond areas, cross overs, and flat areas.

The treated recycled fiber stream (containing wood pulp fibers and synthetic fibers) were introduced into the furnish stream of a wet forming process. The recycled fibers were blended inline with virgin radiata pine pulp fibers (Laja 10 available from CMPC Celulosa of Chile) at a level of 20% by dry weight.

This blend of fibers was formed into a wet sheet having a basis weight of 50 grams per square meter (gsm) utilizing a forming wire available from Albany

International under the designation 84M. The wet sheet was then laid on top of a layer of continuous filament polypropylene spunbond having a basis weight of approximately 24 gsm. The two layers were supported on an hydroentangling wire available from Albany International under the designation 90 BH. The layers were entangled utilizing five manifolds. Each manifold was equipped with a jet strip having one row of 0.005 inch holes at a density of 40 holes per inch. The water pressure was 1100 pounds per square inch gauge and the total time the web was exposed to pressure was 213 microseconds.

The resulting composite sheet was then dried to a final product. The resulting product was compared to a control hydroentangled material made with the same wood pulp and spunbond in the same ratios and under the same conditions but without the recycled fibers. These results are shown in Table 1 below:

TABLE 1

PROPERTIES	Product Without Recycled Material	Product With 20% Recycled Material
Basis Wt	65.7 gsm	66.0 gsm
Thickness	12.88 mils	12.64 mils
CD Trap Tear	1068 grams	1070 grams
MD Trap Tear	1805 grams	1868 grams
CD Drape	3.75 cm	4.21 cm
MD Drape	6.11 cm.	6.09 cm
Pulp Side Abrasion	13.2 cycles	12.7 cycles
Water Capacity	18.4 grams	19.77 grams

A second run was carried out utilizing the same materials and conditions except that pressure used to hydraulically entangle the sample containing the 20% recycled material was increased to 1200 psig. The material was dried in the same manner as before. The resulting properties are shown below in Table 2:

TABLE 2

PROPERTIES	Product Without Recycled Material	Product With 20% Recycled Material
Basis Wt	65.7 gsm	63.5.0 gsm
Thickness	12.88 mils	12.7 mils
CD Trap Tear	1068 grams	1179 grams
MD Trap Tear	1805 grams	2147 grams
CD Drape	3.75 cm	4.31cm
MD Drape	6.11 cm.	6.16 cm
Pulp Side Abrasion	13.2 cycles	17.3 cycles
Water Capacity	18.4 grams	19.10 grams

It is evident from Table 2 that higher entangling pressures may be used with the recycled fibers. These samples demonstrate that recycled synthetic fibers (and additional pulp fibers) may be entangled together with a matrix of continuous filaments to form a hydraulically entangled nonwoven composite structure.

The recycled fibers that have been hydraulically fragmented provide advantages because they are generally uniform and can be readily hydraulically entangled together with and into a matrix of substantially continuous filaments to form a tough, coherent nonwoven composite structure without the flocks and non-uniformities of previous recycled materials formed from bonded fibrous webs. The relatively distorted, twisted and irregular nature of the recycled materials used in the present invention is thought to result in greater efficiency because less material is washed out by the high pressure jets. This is believed to be due, at least in part, to the higher surface area and fiber morphology causing less fiber loss. The structure of the recycled fibers and fiber-like materials offer additional advantages because they are readily adapted to wet-forming processes and have good retention in the forming section. Furthermore, the relative ease with which these recycled fibers can be processed by wet-forming techniques provides a suitably uniform starting material for hydraulic entangling.

A highly uniform entangled nonwoven composite structure offers advantages. A nonwoven composite structure that is highly uniform in appearance tends to be aesthetically pleasing. Less pulp material and/or lighter basis weight substrates may be used without sacrificing the material's ability to mask or cover. In some cases,

certain tensile properties and other physical characteristics may be less likely to have strong variations or localized spots of non-uniformity.

While the present invention has been described in connection with certain preferred embodiments, it is to be understood that the subject matter encompassed by way of the present invention is not to be limited to those specific embodiments. On the contrary, it is intended for the subject matter of the invention to include all alternatives, modifications and equivalents as can be included within the spirit and scope of the following claims.

WHAT IS CLAIMED IS:

1. A hydraulically entangled nonwoven composite structure comprising:

a matrix of substantially continuous filaments; and

a fibrous material comprising recycled synthetic fibers and fiber-like materials having at least one thread element composed of synthetic material including at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid.

2. The hydraulically entangled nonwoven composite structure of claim 1, wherein the thread element has a length ranging from about 1 millimeter to about 15 millimeters.

3. The hydraulically entangled nonwoven composite structure of claim 2, wherein the thread element has a length ranging from about 1.5 to about 10 millimeters.

4. The hydraulically entangled nonwoven composite structure of claim 3, wherein the thread element has a length ranging from about 2 to about 5 millimeters.

5. The hydraulically entangled nonwoven composite structure of claim 1, wherein the irregular distortions are in the form of bends in the thread element, flattened segments of thread element, expanded segments of thread element and combinations thereof.

6. The hydraulically entangled nonwoven composite structure of claim 1, wherein the thread elements of the recycled materials have surface areas that are greater than comparable thread elements in the bonded fibrous material prior to hydraulic fracture of the thread element to separate it from the bonded fibrous material.

7. The hydraulically entangled nonwoven composite structure of claim 6, wherein the surface areas of the recycled thread elements are at least about 5 percent greater than comparable thread elements in the bonded fibrous material prior to

hydraulic fracture of the thread element to separate it from the bonded fibrous material.

8. The hydraulically entangled nonwoven composite structure of claim 1, wherein the synthetic material is a synthetic thermoplastic material.

9. The hydraulically entangled nonwoven composite structure of claim 1, further comprising pulp fibers.

10. The hydraulically entangled nonwoven composite structure of claim 9 comprising:

from about 1 to about 85 percent, by weight, recycled synthetic fibers and fiber-like materials;

from about 15 to about 99 percent, by weight, pulp fibers; and

from about 1 to about 30 percent, by weight, substantially continuous filaments.

11. The hydraulically entangled nonwoven composite structure of claim 1 having a basis weight of from about 20 to about 200 grams per square meter.

12. The hydraulically entangled nonwoven composite structure of claim 1, wherein the recycled synthetic fibers and fiber-like materials are selected from polyesters, polyamides, polyolefins and combinations thereof.

13. The hydraulically entangled nonwoven composite structure of claim 1, wherein the pulp fibers are selected from the group consisting of virgin hardwood pulp fibers, virgin softwood pulp fiber, secondary fibers, and mixtures of the same.

14. The hydraulically entangled nonwoven composite structure of claim 1, further comprising clays, starches, particulates, and superabsorbent particulates.

15. The hydraulically entangled nonwoven composite structure of claim 1, further comprising up to about 3 percent of a de-bonding agent.

16. A wiper comprising one or more layers of the hydraulically entangled nonwoven composite structure of claim 1, said wiper having a basis weight from about 20 gsm to about 200 gsm.

17. The wiper according to claim 16 having a basis weight from about 40 to about 150 gsm.

18. A method of making a hydraulically entangled nonwoven composite structure, the method comprising:

providing a layer of recycled synthetic fibers and fiber-like materials comprising at least one thread element composed of synthetic material having at least one irregular distortion generated by hydraulic fracture of the thread element to separate it from a bonded fibrous material while the bonded fibrous material is suspended in a liquid;

superposing the layer of recycled synthetic fibers and fiber-like materials over a layer of substantially continuous filaments

hydraulically entangling the layers to form a nonwoven web; and

drying the web.

19. The method of claim 18 wherein the steps of providing the layer of recycled synthetic fiber and fiber-like materials and superposing the layer of recycled synthetic fibers and fiber-like materials over a layer of substantially continuous filaments comprises depositing a layer of the recycled fibers and fiber-like materials directly on a layer of substantially continuous filaments by dry forming or wet-forming techniques.

20. The method of claim 19 wherein pulp fibers are included within the layer of recycled synthetic fiber and fiber-like materials.

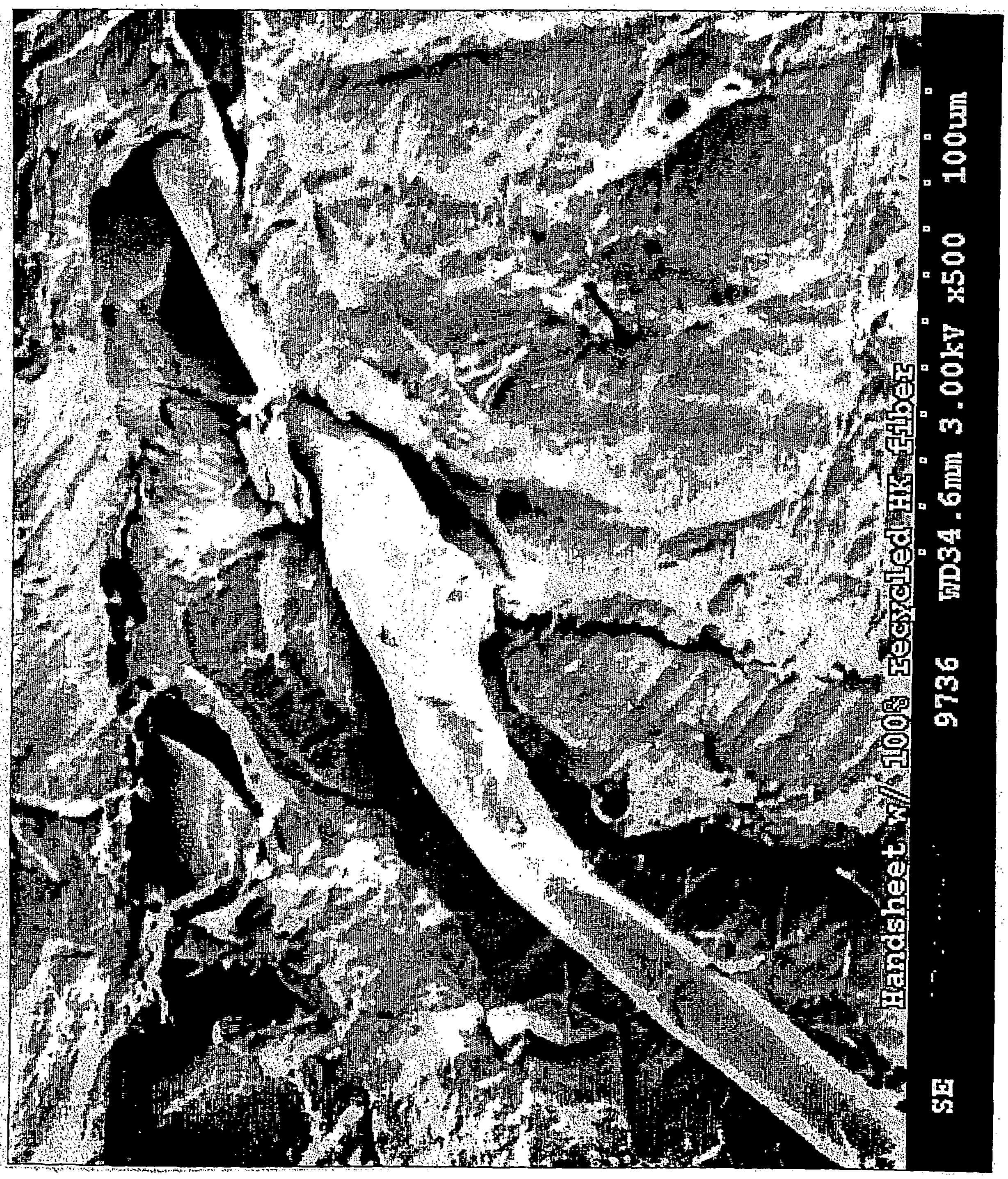
Handsheet w/ 100% recycled HK fiber
SE 9736 WD34.6mm 3.00kV x500 100um

FIG. 1

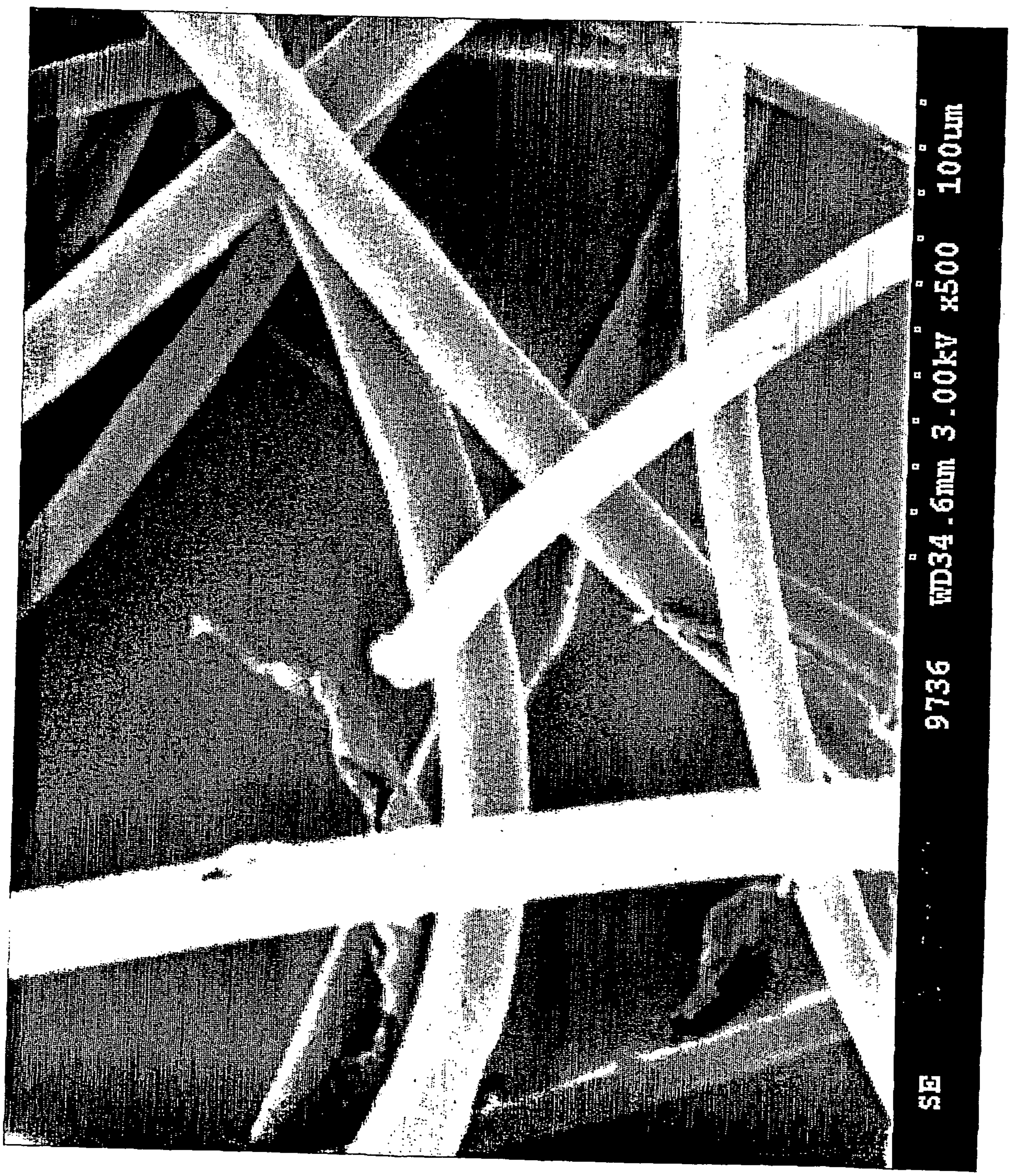

FIG. 2

FIG. 3

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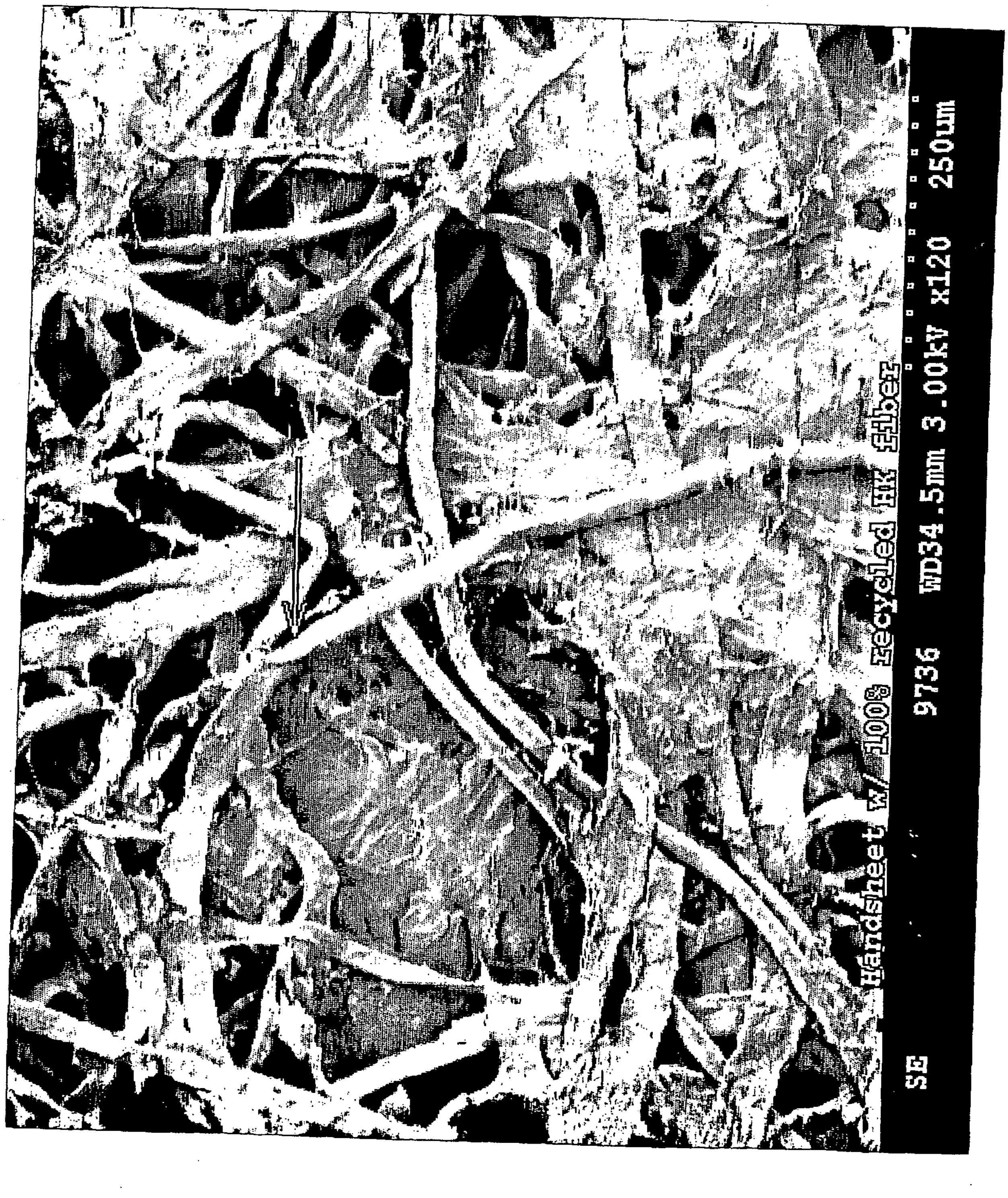
Handsheet w/ 100% recycled HK fiber
9736 WD34.5mm 3.00kV x120 250um
SE

FIG. 4

FIG. 5

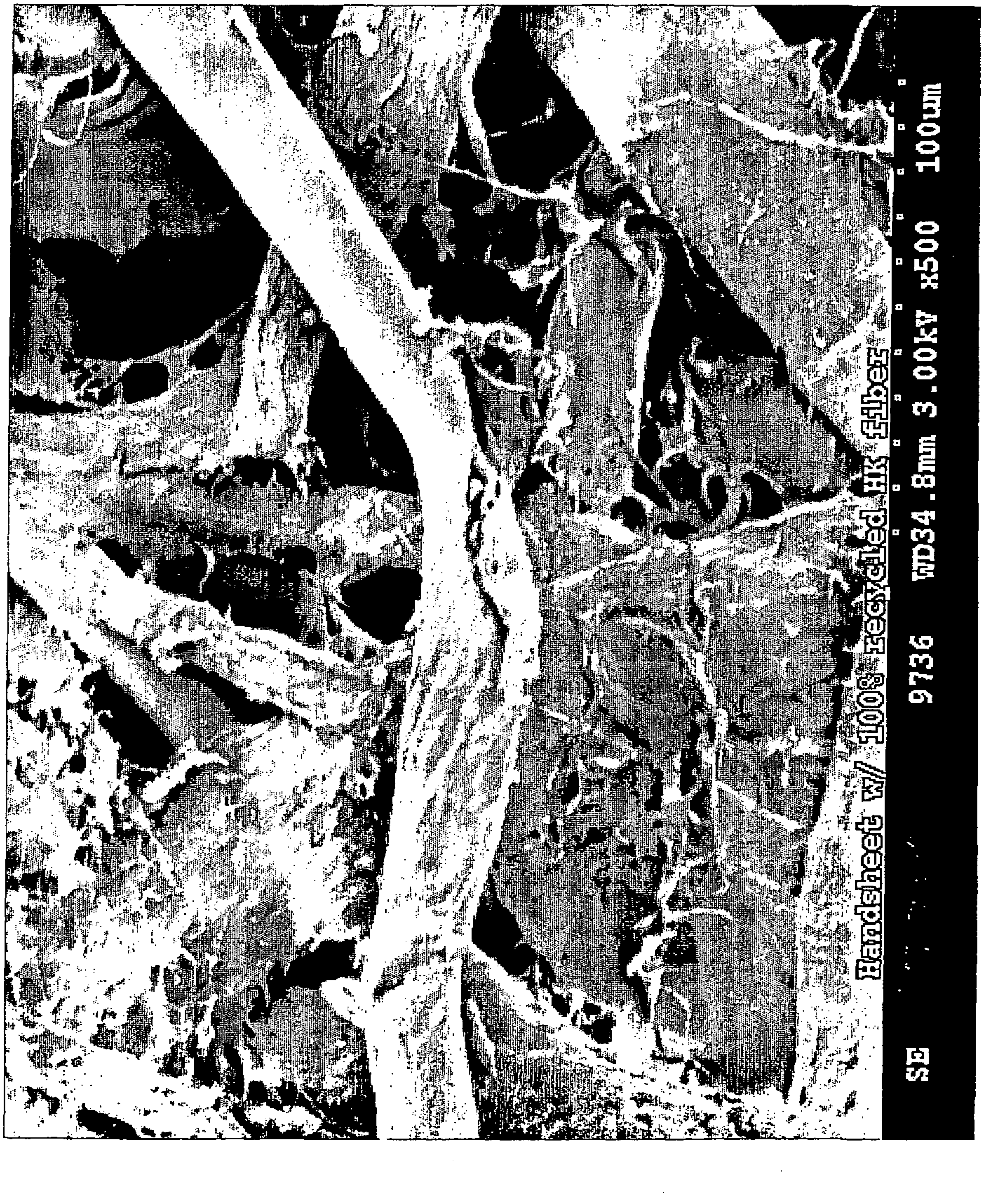
Handsheet w/ 100% recycled HK fiber
SE 9736 WD34.8mm 3.00kV x500 100um

FIG. 6

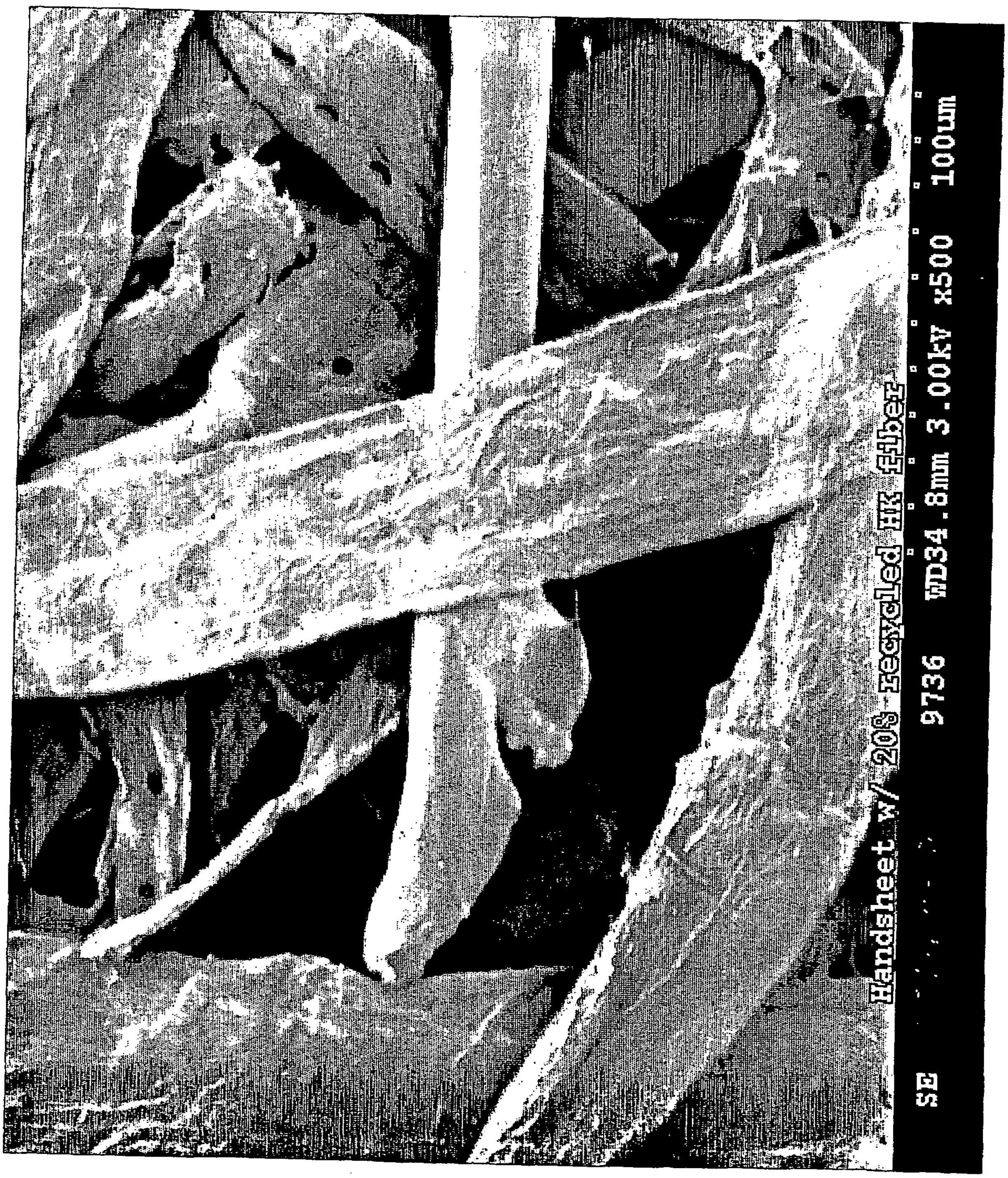
Handsheet w/ 20% Recycled HK Fiber
SE
9736
WD34.8mm 3.00kV x500
100um

FIG. 7

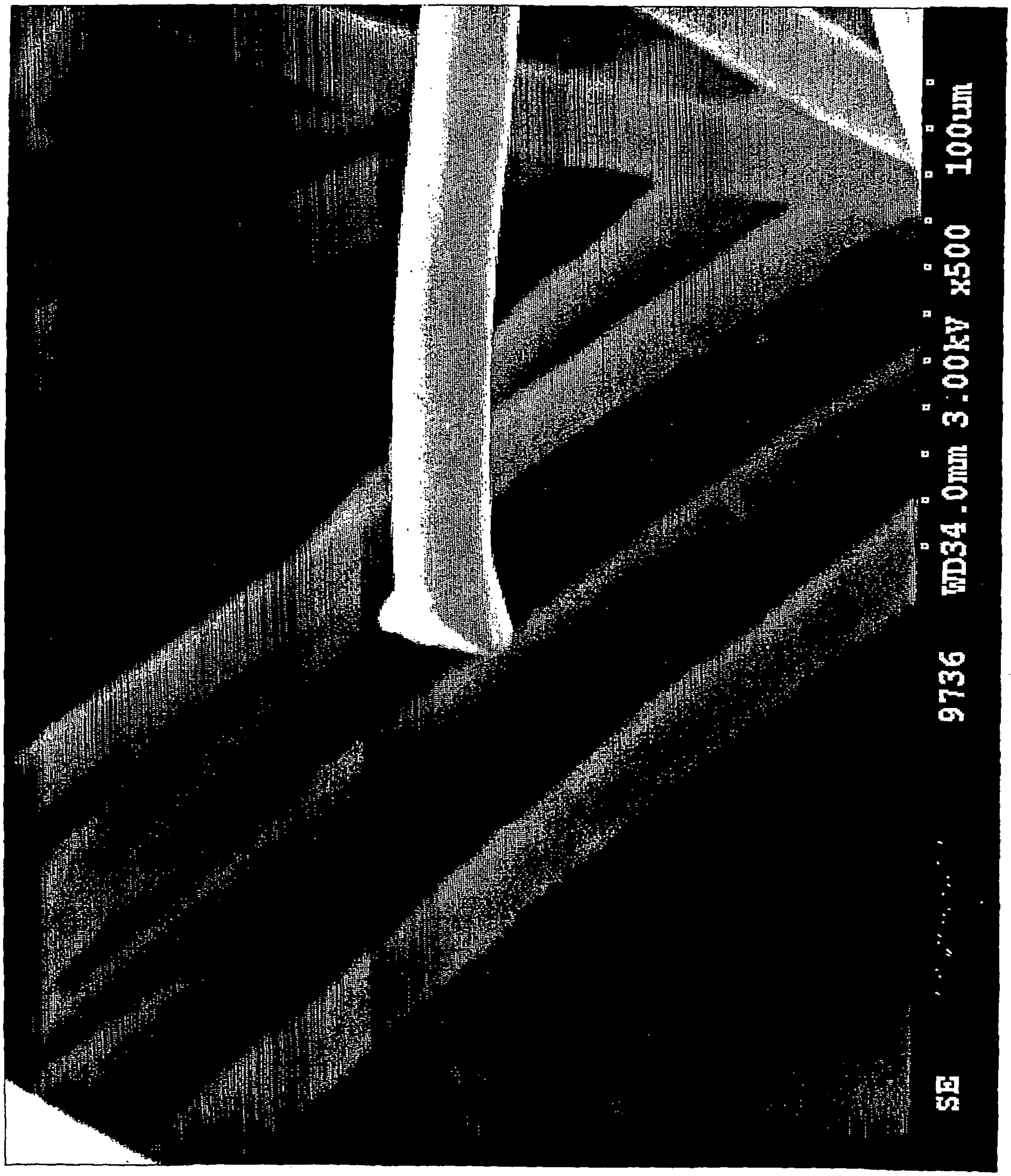

FIG. 8


SE
Handsheet w/ 100% recycled HK Fiber
9736 WD34.6mm 3.00kV x250 200um

FIG. 9

FIG. 10

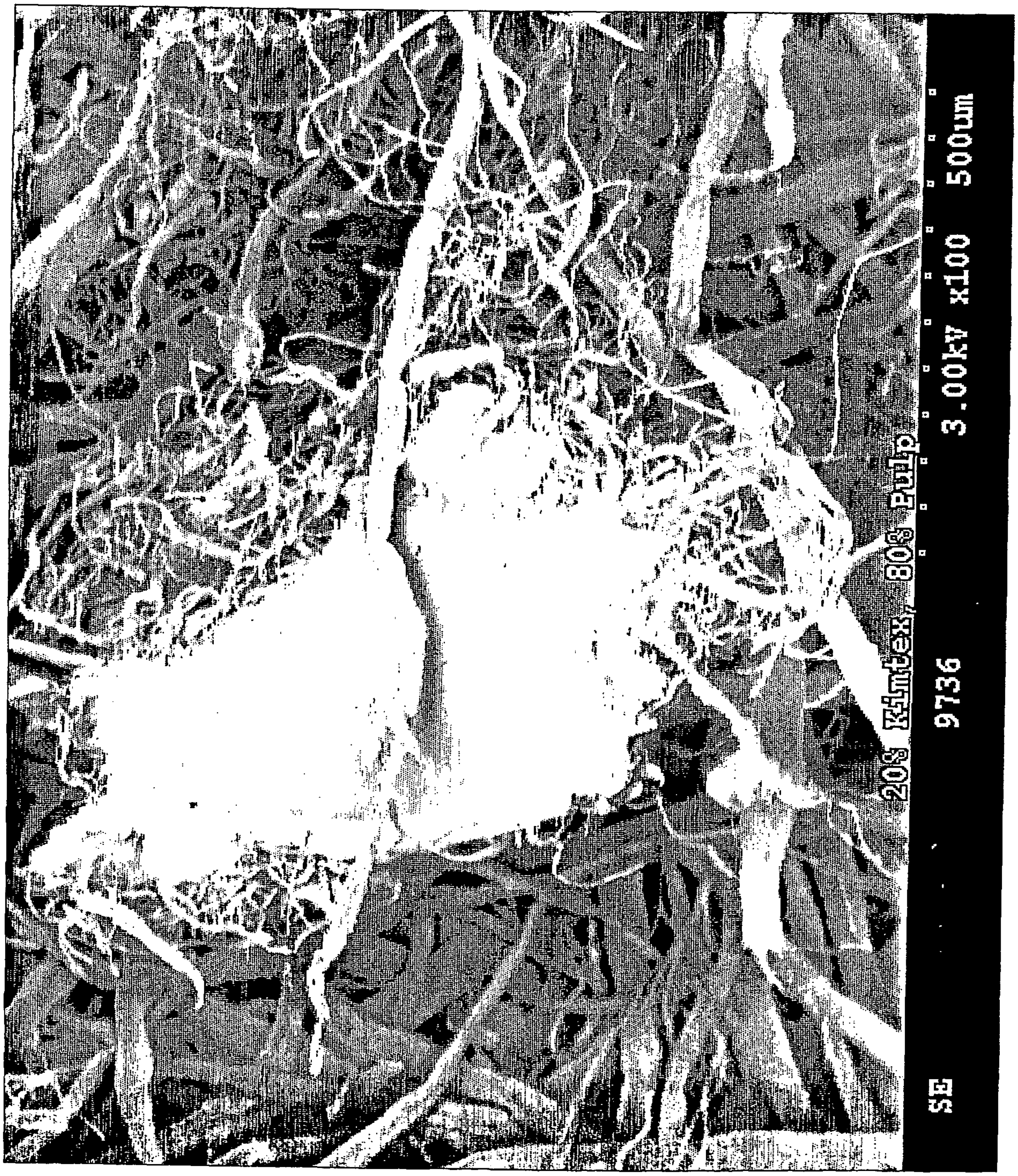

FIG. 11

FIG. 12